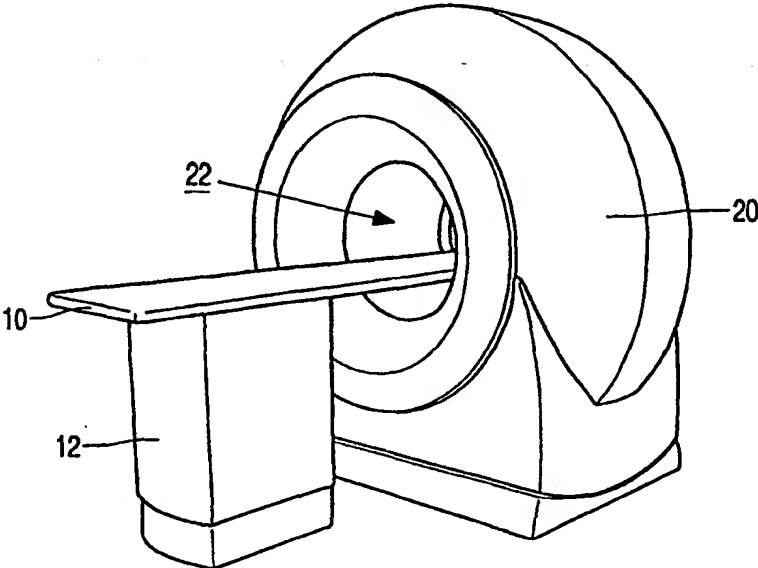


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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/EP99/08950 <b>(22) International Filing Date:</b> 15 November 1999 (15.11.99)  <b>(30) Priority Data:</b> 98203971.1 27 November 1998 (27.11.98) EP  <b>(71) Applicant:</b> KONINKLIJKE PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).  <b>(72) Inventor:</b> MULDER, Gerardus, B., J.; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).  <b>(74) Agent:</b> SCHOUTEN, Marcus, M.; Internationaal Octrooibureau B.V., Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).		<b>(81) Designated States:</b> JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>
<b>(54) Title:</b> MAGNETIC RESONANCE IMAGING SYSTEM  <b>(57) Abstract</b> <p>A magnetic resonance imaging system includes a cylindrically shaped space for receiving a patient to be examined. In conventional MRI systems this space is both long and narrow; this impedes the access to the patient during images and also causes feelings of claustrophobia. The novel MRI system has a cylindrical space which is either short and wide or open at its side, thus providing access for a physician or medical assistant. The open space also reduces feelings of claustrophobia.</p> 		

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Magnetic resonance imaging system.

The invention relates to a magnetic resonance imaging system (MRI system) for forming an image of a human or animal patient, or part thereof, including a mainly cylindrical space for accommodating the relevant part of the patient during imaging, said mainly cylindrical space being bounded by an envelope in which there is arranged a magnet  
5 for generating a static magnetic field in the cylindrical space.

A magnetic resonance imaging system of this kind is generally known in the field of medical diagnosis and is marketed, for example under the name Gyroscan by Philips  
10 Medical Systems. A system of this kind includes a large electromagnet which is generally composed of a number of superconducting coils which are accommodated in a cryostat. A tube having a diameter large enough to receive a patient is formed in the cryostat. This tube constitutes the cylindrical space in which the relevant part of the patient must be accommodated during imaging. The tube typically has a length of 1.8 m or more and an inner  
15 diameter of from 60 to 65 cm. The magnet coils are arranged around the tube so that, when the coils are energized, a steady magnetic field whose field direction extends in the longitudinal direction of the tube is generated in the tube. The aim is to realize a magnetic field of very high homogeneity in the central part of the tube. Furthermore, gradient coils are arranged around the tube in known manner in order to apply temporally switched gradients to the static  
20 and uniform magnetic field. In co-operation with RF transmitter and receiver coils magnetic resonance signals are generated in the body of the patient; these signals are subsequently detected and used to form magnetic resonance images (MR images).

The requirement as regards high homogeneity, necessary so as to enable the formation of high-quality images within a short period of time, causes the magnet to have a  
25 large length in relation to the inner diameter of the coils. The presence of the cryostat and the gradient coils, furthermore, causes the tube to have an inner diameter which is substantially smaller than the inner diameter of the coils; in practice a difference in diameter amounting to 10 cm or more is necessary. Consequently, the patient is poorly accessible for a physician or medical assistant, for example in the case of medical procedures during which an intervention

within the patient is monitored via the MR images. Moreover, the long and comparatively narrow tube induces feelings of claustrophobia in a number of patients so that the formation of MR images is impeded or even becomes impossible.

Even though nowadays so-called open MRI systems are available, such systems  
5 generally have a comparatively poor homogeneity or a comparatively weak magnetic field, i.e. a field which is substantially less than the approximately 0.5 Tesla or more used as a general standard for a general purpose MRI system. Some of the open systems of this kind offer very limited freedom of movement to the physician, i.e. the physician stands between the magnet coils. In other open systems the patient is arranged in a comparatively narrow gap between  
10 poleshoes of large diameter. It is an object of the invention to provide a magnetic resonance imaging system in which the accessibility for the physician is substantially better than in the known systems. To achieve this, the magnetic resonance system according to the invention is characterized as recited in Claim 1. Because of the large opening, an attending physician can readily access the patient from outside the cylindrical space; this also substantially mitigates  
15 the feelings of claustrophobia for patients who are susceptible thereto.

A first embodiment of the magnetic resonance imaging system according to the invention includes the elements recited in Claim 2. This system includes a magnet with a series of coils which are arranged around the cylindrical space for the patient. In comparison with the known MRI systems, this magnet is short and its inner diameter is large so that  
20 a general-purpose MRI system can be realized. Such an MRI system according to the invention typically has a length of 1.1 m and an inner diameter of 65 cm or more. The embodiment of an MRI system as recited in Claim 3 illustrates the feasible dimensions of the coil system ensuring adequate space for the cryostat, the gradient coils and further elements which necessarily have to be arranged between the magnet coils and the cylindrical space for the  
25 patient.

The embodiments according to the Claims 4, 5 and 6 concern an MRI system with a feasible construction of coils whereby a static magnetic field of adequate strength and homogeneity can be achieved.

Known MRI systems often involve so-called active shielding; this means that  
30 outside the magnet coils for generating the static field at the area where the part of the patient to be imaged is situated there is provided a second system of magnet coils which generates a second magnetic field with an opposed field direction. The strength of said second magnetic field is chosen to be such that the two static magnetic fields mainly compensate one another outside the MRI system, so that the area around the MRI system with a relatively large net

magnetic field is small. As a result, extensive and heavy passive shielding, for example by applying iron or another ferromagnetic metal, can be dispensed with or such shielding can be constructed so as to be significantly lighter. The coils for active shielding in the known MRI systems are arranged over a distance which is substantially equal to the largest distance  
5 between the coils forming the magnetic field. A further embodiment of the MRI system according to the invention is recited in the Claims 7 and 8. By making the shielding coils extend over a distance which is shorter than the length of the magnet, the exterior envelope formed by the cryostat may be more compact, so that an MRI system is obtained which is smaller and better suitable in practice for medical procedures during which an intervention  
10 within the patient is monitored via the MR images.

Claim 9 recites another embodiment of an MRI system according to the invention. This system has a cylindrical patient space whose dimensions correspond substantially to the dimensions of a conventional system, i.e. a typical diameter of from approximately 60 to 70 cm and a length of approximately 1.5 m. The accessibility is now  
15 achieved by way of the opening formed in the side wall of the cylindrical space, so that the patient is suitably accessible over substantially the entire length and also is in contact with the physician or medical assistant.

An MRI system of this kind is provided with, for example a coil system as recited in Claim 10. This system is capable of forming a magnetic field of adequate strength  
20 whose zone of adequate homogeneity extends across a large part of the length of the cylindrical space (approximately 105 cm) and has a diameter of approximately 15 cm. A magnet of this kind is particularly suitable for forming images of vascular systems, for example in an arm or a leg of the patient.

25 The invention will be described in detail hereinafter with reference to the drawing; therein:

Fig. 1 is an exterior view of a first embodiment of an MRI system;

Fig. 2 shows diagrammatically a first system of magnet coils for use in the first  
30 embodiment;

Fig. 3 shows diagrammatically an alternative system of magnet coils;

Fig. 4 is an exterior view of a second embodiment of an MRI system;

Fig. 5 shows diagrammatically a set of magnet coils for use in the second embodiment.

Fig. 1 is an exterior view of a first embodiment of an MRI system according to the invention. The Figure shows the patient table 10 of the MRI system and also the magnet system which is surrounded by an envelope 20. The magnet system is composed of a number of ring-shaped magnet coils which enclose a cylindrical space 22 in order to generate a static and uniform magnetic field in the cylindrical space. Gradient coils for superposing gradients on the static magnetic field are also arranged within the envelope. As is known to those skilled in the art, gradients of this kind are indispensable for forming magnetic resonance images. The magnets are generally superconducting electromagnets which are accommodated in a cryostat within the envelope in order to realize and sustain a low temperature for the magnet coils so that superconduction occurs.

The patient table 10 is supported by a base 12 in which there is provided, for example a drive whereby the patient table and a patient accommodated thereon can be moved into and out of the cylindrical space 22. Further displacements in the vertical and transverse directions are also feasible, depending on the necessity of moving certain parts of the patient into the center of the magnet and/or to facilitate the positioning of the patient on the table. The Figure does not show inter alia the equipment necessary for cooling the magnet coils, the power supplies for energizing the magnet coils and gradient coils, the RF coils for realizing and receiving the magnet resonance signals and the data processing equipment for controlling the gradient coils and RF coils and for reconstructing and displaying magnetic resonance images.

In comparison with conventional MRI systems, the length of the magnet shown is short and the diameter of the cylindrical space 22 is large. In a system which is proportioned for the imaging of the thorax, for example for cardiological applications, the diameter amounts to approximately 70 cm and the length to approximately 110 cm. In the case of these dimensions the head of a patient of normal build is situated almost outside the magnet when the heart is positioned at the center. Moreover, the patient can be moved in the vertical and the transverse direction within the cylindrical space in order to position a specific part of the patient, for example, the heart, at the center of the magnet. Because the magnet is short and the diameter of the cylindrical space is large, the patient is rather well accessible for a physician or a medical assistant standing besides the magnet. The accessibility can be further enhanced by slightly tilting the patient table or the magnet so that the longitudinal direction of the table no longer extends parallel to the axis of rotation of the cylindrical space.

Fig. 2 shows diagrammatically an embodiment of a coil system for such a short MRI system. The coil system consists of a number of ring-shaped coils and is rotationally

symmetrically situated about an axis  $z-z'$ ; only the cross-section of the coils with a half plane bounded by the axis of rotation is shown. Hereinafter a tubular coil is to be understood to mean a ring-shaped coil for which the difference between the radius of the inner surface and that of the outer surface is smaller than the length of the coil in the axial direction, whereas a disc-shaped coil is to be understood to mean a ring-shaped coil for which the difference between the radius of the inner surface and that of the outer surface is larger than the length of the coil in the axial direction, and a square coil is to be understood to mean a ring-shaped coil for which these two distances are approximately equal. The coils need not have a rectangular cross-section (a so-called square coil may also have a round cross-section).

The coil system which is diagrammatically shown in Fig. 2 includes six coils which form magnetic fields and are denoted by the reference numerals 31, 32, 33, 34, 35 and 36. The coils are made, for example of a material which is superconducting at low temperatures, for example NbTi/Cu. The two outer coils (31 and 32), viewed in the axial direction, are disc-shaped and constitute the most important coils for the formation of the static magnetic field. In terms of ampere turns these two coils carry the major part of the electric current. Two tubular coils 33 and 34 and two square coils 35 and 36 of smaller diameter are arranged within said disc-shaped coils. In terms of ampere turns the tubular coils 33 and 34 carry a comparatively small amount of current, be it in the direction opposing the current direction in the coils 31 and 32. This current in the opposite direction significantly enhances the homogeneity of the steady magnetic field. The current direction in the two square coils 35 and 36 is the same as that in the disc-shaped coils 31 and 32; they carry a current which is slightly larger than that in the tubular coils 33 and 34. The tubular coils 37 and 38 are shielding coils and serve to compensate the steady magnetic field outside the MRI system (the stray field); each of these shielding coils carries a current which amounts to approximately half the current in the disc-shaped coils and flows in the opposite direction. These coils have a large diameter but an axial length which is shorter than the distance between the two disc-shaped coils 31 and 32. As a result, the envelope may be given an oblique or round shape so that the appearance of the system becomes less bulky and more comfortable to work with for a physician or assistant.

Fig. 3 shows diagrammatically a second embodiment of a coil system for an MRI system according to the invention. This system again includes six current-carrying coils which form magnetic fields and are denoted by the reference numerals 41, 42, 43, 44, 45 and 46. The two outer coils 41 and 42, viewed in the axial direction, are disc-shaped and again constitute the most important coils for building up the static magnetic field and carry the major

part of the electric current in terms of ampere turns. Within these disc-shaped coils there are arranged four tubular coils 43, 44, 45 and 46 of smaller diameter. The coils 43 and 44 notably serve to enhance the homogeneity and in terms of ampere turns they carry a comparatively small amount of current in the direction opposing the current direction in the coils 41 and 42.

5 The current direction in the two tubular coils 45 and 46 is the same as that in the disc-shaped coils 41 and 42; they carry a current which is slightly smaller than that in the tubular coils 43 and 44. The properties of the static magnetic field can be further improved by the inclusion of annular conductors which do not carry a current, for example iron tubular conductors 47 and 48. These tubular conductors, for example are not cooled and are arranged outside the cryostat.

10 Thus, in practice the diameter of the cylindrical space (22 in Fig. 1) is not reduced or only hardly so, because the cryostat occupies a volume of given thickness relative to the coils 43 to 46. In order to compensate the external stray field there is provided a single tubular coil 49 having a large diameter but a short axial length. This coil carries a current which is almost equal to the current in each of the disc-shaped coils 41 and 42.

15 Fig. 4 shows a second embodiment of an MRI system according to the invention. The static magnetic field is generated by means of a magnet which is accommodated in a C-shaped or U-shaped envelope 52 having a length which is comparable to the length of an adult. The C-shaped or U-shaped envelope is open at its ends and on one side also over a substantial part of its length, being the entire length in the Figure. A patient on  
20 a patient table 51 can be moved into the magnetic field via one of the ends. Because the magnet is open on one side, the patient is accessible for a physician or medical assistant and the feelings of claustrophobia are also reduced. The zone of homogeneity of such a magnet is very long and its diameter can be sufficient for the simultaneous imaging of a large part of an arm, leg or part of the torso of the patient. Consequently, this magnet shape is very suitable for  
25 the three-dimensional imaging and treatment of the vascular system of the patient. In order to enable monitoring of an interventional procedure, for example, the MRI system may be provided with a display screen 55. The display screen should evidently be of a type which operates in the presence of a magnetic field, for example an LCD, and it should also be adequately shielded so as to avoid disturbances in the RF receiving coils. Like Fig. 1, this  
30 Figure does not show the equipment for cooling the magnet coils, the power supplies for energizing the magnet coils and gradient coils, the RF coils for realizing and receiving the magnetic resonance signals, and the data processing equipment for controlling the gradient coils and RF coils and for reconstructing magnetic resonance images.

Fig. 5 shows a feasible configuration of a magnet coil system for use in the above MRI system. The system is composed of a large number of parallel conductors, eight of which are shown and denoted by the reference numerals 61 to 68 in the Figure. The parallel conductors are interconnected in a two by two fashion by arc-shaped (C-shaped or U-shaped) conductors which are denoted by the reference numerals 71 to 78. The parallel, substantially straight conductors 61 and 62 which are arranged to both sides of a symmetry plane of the magnet system are interconnected by the C-shaped conductors 71 and 72. The straight conductors 63 and 64 are interconnected by the arc-shaped conductors 73 and 74 which cover a smaller arc than the conductors 71 and 72. The arc-shaped conductors 75 and 76, constituting a coil in conjunction with the straight conductors 65 and 66, have a shorter arc again, like the conductors 77 and 78 which constitute a coil in conjunction with the straight conductors 67 and 68. The direction of the steady magnetic field in such a configuration will be parallel to the symmetry plane of the coil system, perpendicular to the straight conductors 61 to 68. Adequate homogeneity is achieved when the current in the coils gradually increases as the distance between the symmetry plane (small current) and the straight conductors increases. The maximum current strength occurs in the coils whose straight conductors enclose an angle of approximately  $65^\circ$  relative to the symmetry plane, viewed from the axis of the cylindrical space. The coils which enclose a larger angle with respect to and are situated at a larger distance from the symmetry plane carry somewhat less current again. In the vicinity of the side opening the current must be slightly stronger again in order to compensate for the absence of conductors in the opening; consequently, it may be that the maximum current intensity occurs in the conductor situated nearest to the opening.

## CLAIMS:

1. A magnetic resonance imaging (MRI) system for forming an image of a human or animal patient, or a part thereof, including a mainly cylindrical space for accommodating the relevant part of the patient during imaging, said mainly cylindrical space being bounded by an envelope in which there is arranged a magnet for generating a steady magnetic field in the cylindrical space, characterized in that the envelope is provided with an opening which is situated between the cylindrical space and the environment of the magnetic resonance imaging system and has, in at least one direction, a dimension which amounts to at least 50% of the dimension of the cylindrical space in the direction transversely of the opening.

2. A magnetic resonance imaging system as claimed in Claim 1, in which the cylindrical space is mainly rotationally symmetrically shaped around an axis of rotation, is provided with at least one opening in the axial direction, and has a diameter amounting to at least 55% of the length.

3. A magnetic resonance imaging system as claimed in Claim 2, in which the magnet includes a number of coils which form magnetic fields and are arranged around the cylindrical space in order to carry an electric current so as to generate the steady magnetic field, characterized in that the smallest inner diameter of the coils amounts to at least 80% of the largest distance between the coils in the axial direction.

4. A magnetic resonance imaging system as claimed in Claim 3, in which the magnet includes at least four magnetic field forming coils which are arranged in different positions in the axial direction, the two outer coils, viewed in the axial direction, being disc-shaped (having a dimension in the axial direction which is smaller than that in the radial direction).

5. A magnetic resonance imaging system as claimed in Claim 4, in which at least two of the other magnetic field forming coils of the magnet have a tubular shape (have a dimension in the axial direction which is larger than that in the radial direction).

6. A magnetic resonance imaging system as claimed in Claim 4, in which the magnet includes at least six magnetic field forming coils which are arranged in different positions in the axial direction, at least two of the coils being connected so as to carry an electric current in a direction which opposes the current direction in the other coils.

5

7. A magnetic resonance imaging system as claimed in Claim 4, in which the magnet is provided with a shielding system with at least one shielding coil for counteracting the external stray field, said shielding system having a tubular shape, an inner diameter which is larger than the largest outer diameter of the magnetic field forming coils, and an axial  
10 dimension which is smaller than the distance between the two outer magnetic field forming coils.

8. A magnetic resonance imaging system as claimed in Claim 7, in which the shielding system includes a single shielding coil which has an axial dimension amounting to at  
15 the most 50% of the distance between the two outer magnetic field forming coils.

9. A magnetic resonance imaging system as claimed in Claim 1, in which the magnet partly encloses the cylindrical space in the radial direction and the opening extends over at least 65% of the length of the cylindrical space, in the axial direction.

20

10. A magnetic resonance imaging system as claimed in Claim 9, in which the magnet includes magnetic field forming coils, each of which is composed of substantially straight, parallel conductors which are arranged to both sides of the opening and are interconnected at their ends by way of a C-shaped or U-shaped conductive arc.

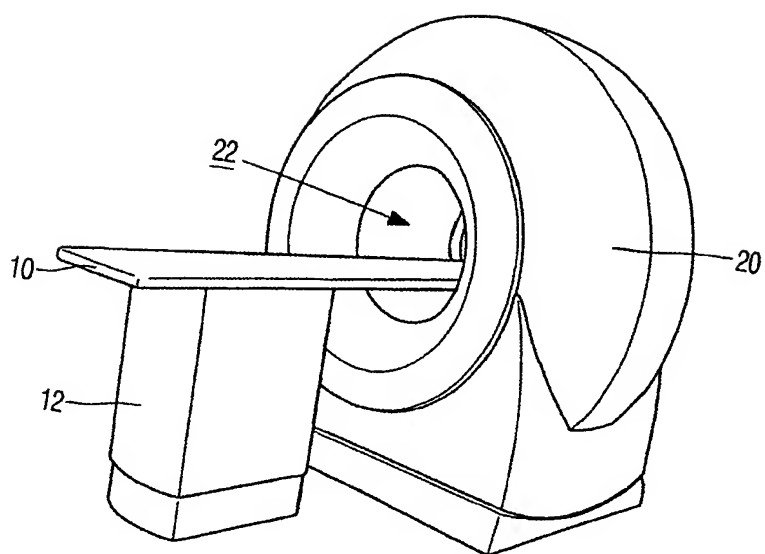


FIG. 1

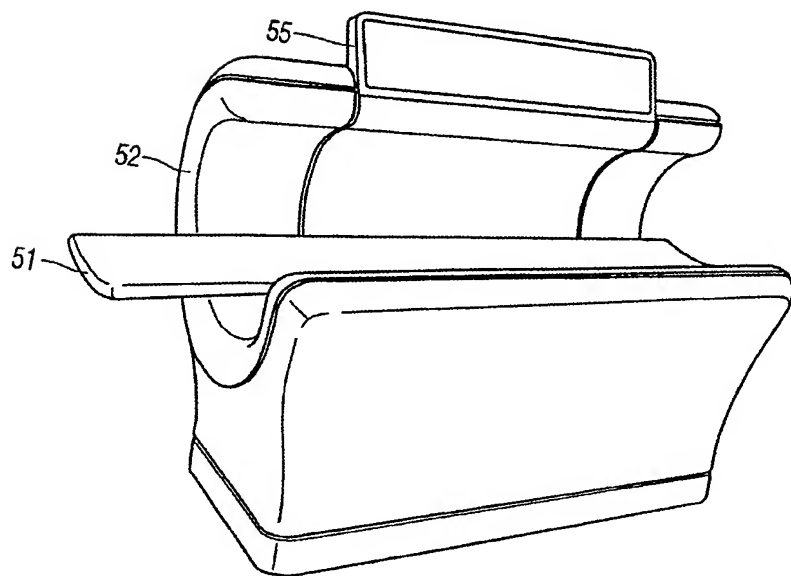
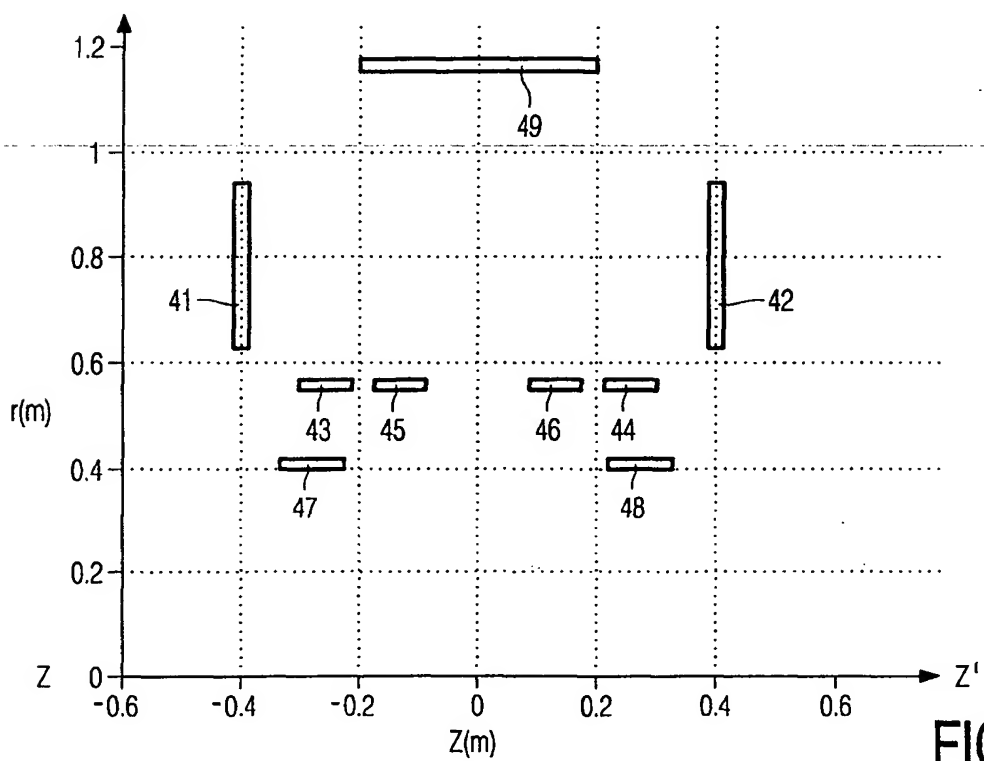
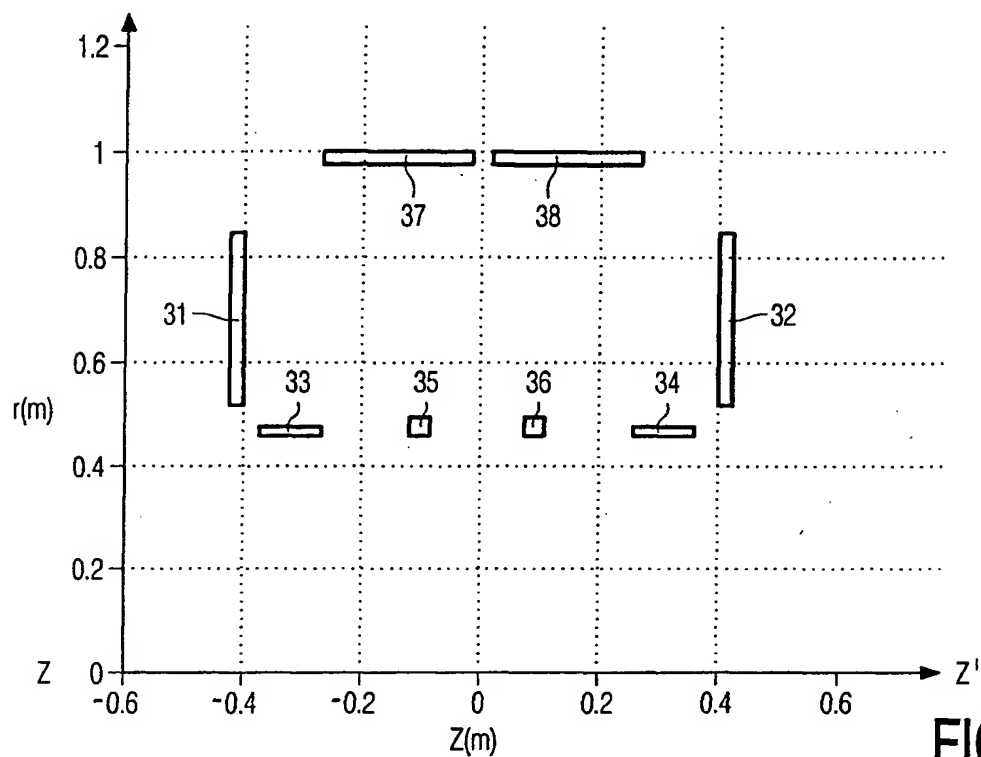


FIG. 4

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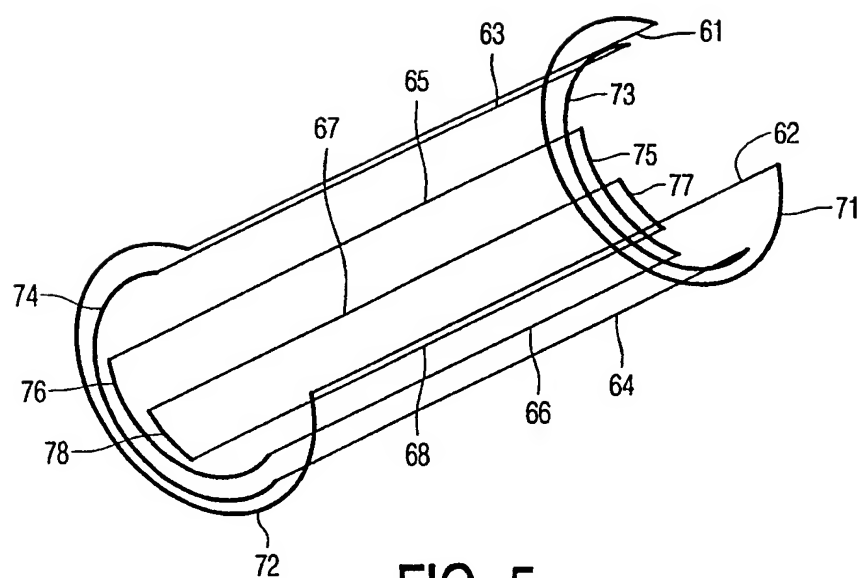


FIG. 5

# INTERNATIONAL SEARCH REPORT

Intern. Application No

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## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01R33/38

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IPC 7 G01R

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0 460 762 A (N.V. PHILIPS' GLOEILAMPENFABRIEKEN) 11 December 1991 (1991-12-11)	1-3, 9
A	column 1, line 58 -column 5, line 14 figures 2,3	4-8
X	US 5 708 362 A (G. FRESE, M. SELLERS) 13 January 1998 (1998-01-13) column 1, line 39 -column 4, line 56 figures 1-4,7	1, 2, 9, 10
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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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